D.4 Coastal Flooding Analyses and Mapping: Pacific Coast

This section of Appendix D provides guidance for coastal flood hazard analyses and mapping that are specific to the Pacific Coast of the United States, generally referred to as "guidelines". The procedures described in this section were developed by a Technical Working Group (TWG) assembled by the Federal Emergency Management Agency (FEMA) in October 2003. They are intended to provide guidance that is generally independent of other Appendix D sections, and that is based on the specific physical processes that influence coastal flooding on the Pacific Coast.

This section focuses on the Pacific Coast from California's border with Mexico to the State of Washington's border with Canada, as shown in Figure D.4.1-1. The coastline of the States of Alaska and Hawaii, and other islands in the Pacific Ocean are subject to unique meteorological conditions and physical processes that are important to coastal flooding, but are not specifically addressed in this version of Section D.4. However, much of this section is considered applicable in these geographic areas if engineering methods and judgment that address geographically unique processes or settings are applied to supplement the procedures described. In addition, some procedures may be applicable to specific settings in other geographic areas of the United States.

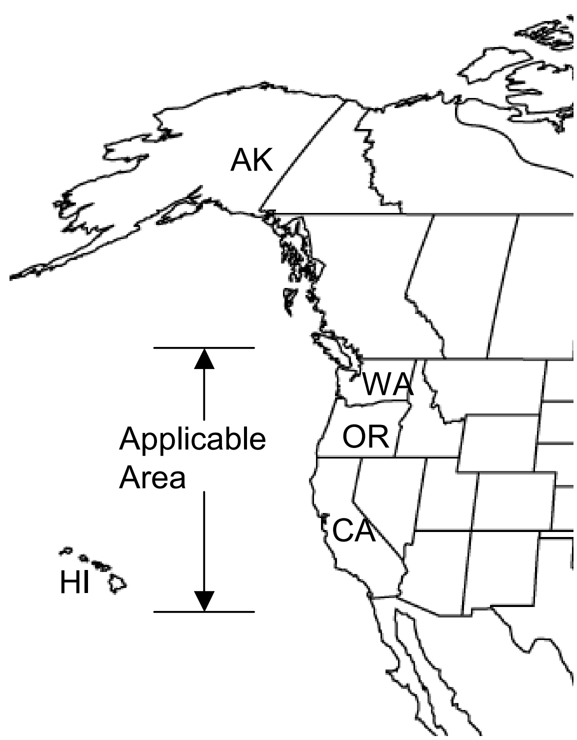

Figure D.4.1-1. Applicable Area – Pacific Coast Guidelines

D.4.1 Pacific Coast Guidelines Overview

Section D.4 is organized to:

- Present background information (Section D.4.1);
- Provide guidance on selecting study methodologies (Section D.4.2);
- Provide a set of technical methods as potential tools to be used in various study settings (Sections D.4.3 to D.4.8);
- Provide guidance on flood hazard mapping (Section D.4.9);
- Provide guidance on study documentation (Section D.4.10); and
- Provide reference information (Sections D.4.11 to D.4.14).

Figure D.4.1-2 shows the general layout of the document. Because it is anticipated that few readers will use the guidance by reading sequentially from beginning to end, Section D.4.2 provides a framework for overall study methodologies that Mapping Partners can use to refer to more detailed analysis methods in subsequent subsections. In many cases, multiple methods are presented for analysis of a single coastal process, and several coastal processes must be analyzed from offshore to onshore to produce hazard zone designations for a coastal Flood Insurance Study (FIS). Section D.4.2 provides guidance on selecting analysis methods that are applicable to particular coastal settings and on linking the analysis of individual coastal processes together in a study methodology. In this sense, the document is organized with a set of general instructions in Section D.4.2, and a toolbox for selection of specific methods in Sections D.4.3 to D.4.8. The appropriate tools must be selected based on study objectives, coastal exposure, geomorphic setting, and available data.

Coastal flooding on the Pacific Coast is a product of combined offshore, nearshore, and shoreline processes. The interrelationships of these processes are complex, and their relative effects vary significantly with coastal setting. These complexities present challenges in the determination of the 1% annual chance flood for FEMA hazard mapping purposes. The fundamental philosophy of this section is to provide a set of technical tools that can be selected and applied as needed to match specific site conditions and physical processes relevant to coastal flood hazards.

These guidelines offer insight and recommended methods to analyze complex Pacific coast flood processes in a reasonable way. However, they require technical judgment and experience in their application, and are not a prescriptive technique that can be applied uniformly in all study areas. The guidelines are intended to apply to a range of settings, but they cannot address all settings and conditions due to the broad variability of the Pacific Coast. They include new methods that

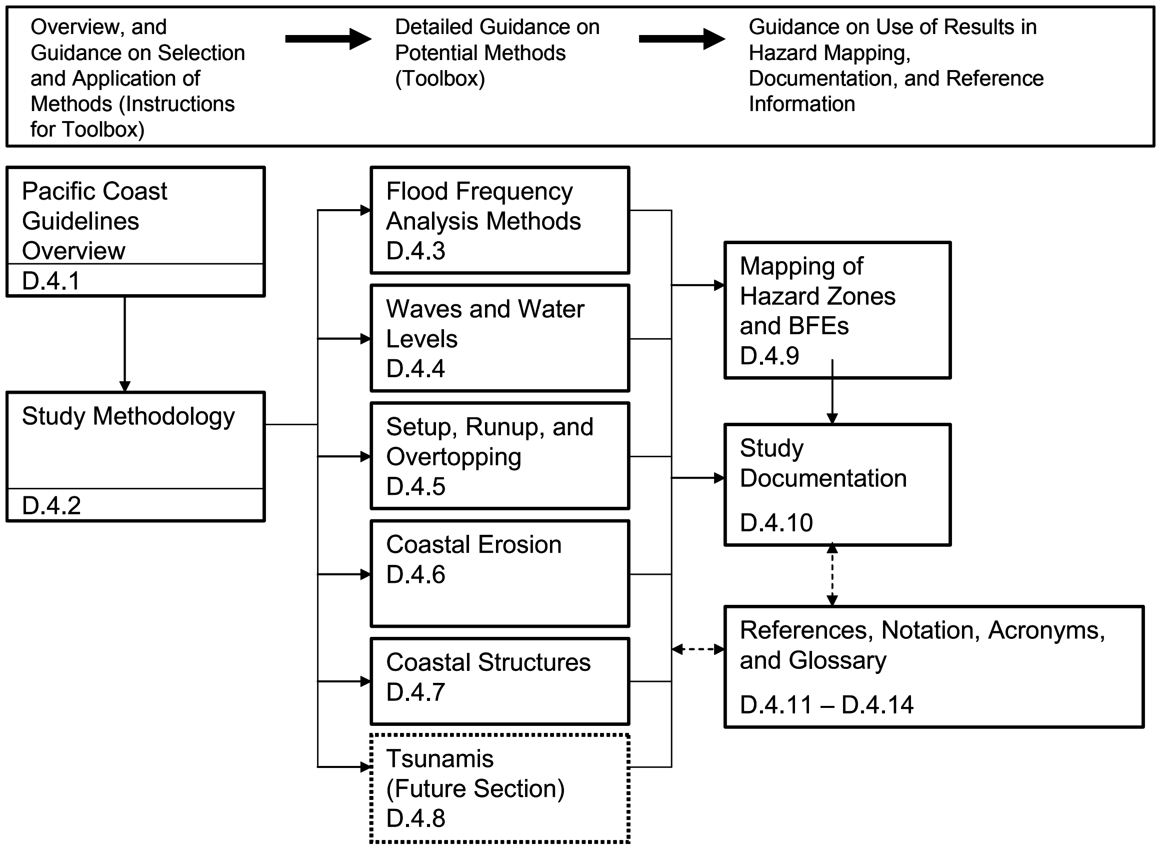

Figure D.4.1-2. Pacific Coast Guidelines Overview

were developed over a one-year period by the TWG assembled by FEMA. Methods were selected and developed to be robust and reproducible, but at the release date of this document (November 2004), many of these methods have not been fully tested in FISs. Application of experience and judgment in coastal engineering is necessary to apply the procedures described. The Mapping Partner may determine that minor modifications or deviations from these guidelines are necessary to adequately define the coastal flooding conditions and map flood hazard zones in specific areas. In these cases, documentation of these differences is required as part of intermediate and final study submittals.

Other appendices provide specific information on subjects such as study scoping (Appendix I), aerial mapping and surveying (Appendix A), treatment of levee systems (Appendix H), formats for FIS reports and rate maps (Appendices J and K), formats for draft digital data and Digital Flood Insurance Rate Map (DFIRM) databases (Appendix L), guidance for technical and administrative support data (Appendix M), and draft data capture standards and guidelines (draft Appendix N). The guidance provided here is intended only to supplement these sections with information specific to coastal flooding on the Pacific Coast. The Mapping Partner shall refer to other appendices where specific guidance is required on technical elements common to most FISs.

Subsections D.4.1.1 and D.4.1.2 provide an overview of the Pacific Coast setting relevant to flood hazards and an introduction to FISs for the Pacific Coast, respectively.

D.4.1.1 Pacific Coast Setting and Characteristics

The Pacific Coast of the contiguous United States is approximately 1,000 miles in overflight length, but significantly longer when inlets, bays, headlands, and islands are considered. It encompasses a broad spectrum of geological and biological provinces.

The overall geology is determined by the existence of tectonic activity throughout, in sharp contrast to the Atlantic and Gulf coasts (Inman and Nordstrom, 1971). On the Pacific Coast, active faults marking tectonic plate boundaries cross the coastline in a number of locations. Subduction zones (continental plate riding over downward-plunging oceanic plates) are found in the northern half. The leading edge of the Pacific Coast is marked by very narrow and steep continental shelves with oceanic depths often found within a few miles of the shoreline. Southern California, a fragment of continental crust attached to the largely oceanic Pacific Plate, has widely varying coastal geology caused by the collection of plate fragments during tectonic collisions in the distant past. Although it has the characteristic narrow continental shelf, the Southern California Bight is marked by a large number of offshore islands and banks rising sharply out of deep water more than 60 miles offshore. This results in partial to nearly complete sheltering of some sections of this 200-mile-long coast from wave energy arriving from certain directions, and produces one of the most complex wave environments in the world.

A string of near-coast mountain ranges is almost continuous along the Pacific Coast. The subduction of the oceanic Pacific Plate under the North American Plate in Washington and Oregon results in volcanic activity well inland from the coast and its influence on the coastal setting is a slow uplift of the land, tending to partially offset the worldwide increase in sea level. Coastal mountain ranges have a profound effect on the geology of the shoreline. The majority of the Pacific Coast's length is comprised of rocky headlands and steep slopes dropping directly to the shore.

The Pacific Coast is ice-free in spite of the high latitude of its northern boundary because of the moderating effects of the south-flowing current, which originates as the warm Kuroshio Current, that cools as it traverses the Northern Pacific. It is broad and slow near the end of its path compared to the relatively narrow and fast-flowing character near its origin. As a result, the North Pacific current (it carries a variety of local names) has negligible effect on the intensity or direction of storm waves reaching the Pacific Coast.

Pacific Coast tides are semidiurnal (two highs per day) and have a range of about 6 feet in the south increasing to about 9 feet in the north.

The Pacific Coast, on the eastern rim of a very long wave-generating fetch, is in the path of the westerly winds that dominate the weather in the Northern Temperate Zone. This results in swell and storm waves with very long periods, greater than 20 seconds in major storms. Antarctic-generated swell, with a number of potential great circle paths, results in low southern swell on the Pacific Coast throughout the year, most obvious during the summer when northern hemisphere waves are at a minimum.

The dominant storm waves result from winter storms initiated south of the Aleutian chain. The fetch is often more than 600 miles, such that wave height and period are controlled by wind speed and duration. Because these storm paths are at a low angle to the general coastline trend, the wave energy impacting a particular location is highly variable. In general, these winter storms produce the highest waves in the northwest and the lowest in the Southern California Bight, which is protected by the abrupt coastal direction change at Point Conception and the offshore islands. Thus, the typical La Niña conditions (intervals between El Niños) provide low southern swell in summer with occasional local storms and a series of major wave events with long peak periods during the winter months (December through March or April.)

The El Niño of 1982-83, the strongest such global climate oscillation in recorded history, resulted in several record-breaking storm wave events, extensive structural damage, and severe erosion (Seymour et al., 1984). During El Niño episodes, for intervals of a year or two, the trade winds normally blowing towards the west near the equator weaken or reverse. This causes a slow sloshing of the Pacific Ocean towards the east and an increase in local sea level that can be as great as 1.5 feet. More significantly, a series of winter storms are spawned north of the Hawaiian Islands with paths directed towards the Pacific Coast. The 1982-83 storms approached the Southern California Bight from almost exactly west, resulting in extreme flooding and wave impact damage on this coast and slightly lower waves impacting the Northwest. The El Niño of 1997-98, steered on a more northerly track by continental high pressure areas, resulted in larger waves in the Northwest than in Southern California (Komar, 1998). The largest waves recorded off Southern California occurred in a La Niña year resulting from a very tight and intense storm initiated close to the coast in January 1988, which moved rapidly onshore (Shore and Beach, 1989). The largest waves recorded off the North Pacific Coast in the last century also occurred in a La Niña interval (Allen and Komar, 2000). Major storms along the Pacific Coast, regardless of the wave generation area, typically persist for 3 to 4 days.

Exposure to long waves generated anywhere in the Pacific Ocean yields the potential for tsunami impacts anywhere on the Pacific Coast; however, much of the seacoast is protected from extensive tsunami flooding by cliffs, steep coastal slopes, or deep water very close to shore. The magnitude of the amplification at the shoreline of the modest deep water tsunami wave heights is dictated by local bathymetry. Flooding risk from tsunamis is highly variable along the coast. One such susceptible location, Crescent City, in Northern California, suffered substantial damage in 1964 from a tsunami initiated by an earthquake in Alaska (Kanamori, 1970).

The Pacific Coast can be divided into two rainfall regimes. North of Monterey Bay, precipitation is greater and snow accumulation is heavy and reliable on inland mountain peaks, such that rivers flow year-round and spring floods are common. South of this point, rainfall is restricted to the winter months and declines in magnitude with reduced latitude. Rivers flow only in the winter and flooding is highly episodic. Except at San Francisco Bay, all of the Pacific Coast rivers discharge directly into the Pacific Ocean. Because the sediment load-carrying capacity is strongly related to both rainfall in the watershed and flooding intensity in the river system (Inman and Jenkins, 1999), the supply of sand to the coastline grades from a maximum in the north to a minimum in the south. The combination of this sand supply condition, the varying coastal geology, and the north-south gradient in wave energy levels results in very different beach configurations in the two rainfall provinces.

North of Monterey, beaches are found in the lowered valleys at the mouths of streams or rivers that flow year-round. The sizes of the accompanying spits are related to the sediment capacity of the streams. South of Monterey Bay and extending to Point Conception, a series of beaches and accompanying dune fields exist as large (10-15 miles long) crescentic bays anchored on the north by large rocky headlands. Beginning at Point Conception and continuing south and east to the border with Mexico are a series of more or less continuous beaches, broken into littoral cells by rocky headlands (such as Palos Verdes, Fermin, Dana and La Jolla points), most in the order of 60 miles in length (Inman and Frautschy, 1966). Thus, the vast majority of the sandy beaches on the Pacific Coast are found in a region that is slightly more than 20% of the total coastline. Their existence in the area with the lowest potential for delivering sand to the coastline owes entirely to the reduced incident wave energy related to latitude and to the substantial wave barriers provided by Point Conception and the offshore islands.

Relevant to FEMA FISs, the dominant coastal flood-related hazards differ substantially for the Pacific Coast from those on the Atlantic and Gulf coasts. Whereas the dominant source of coastal hazards on the Atlantic and Gulf coasts is associated with large storm surge (up to 20+ feet) caused by high wind stresses over broad and shallow continental shelves, the narrow continental shelves of the Pacific Coast preclude surges greater than a few feet. Here, however, large waves with long periods can cause both static and oscillating elevation of the water levels at the shore. The combination is referred to as “wave runup”. The oscillating component of wave runup can have periods from tens of seconds to several minutes. Wave runup and the energy of large breaking waves contribute to coastal hazards and can cause significant beach erosion and structural damage. Because Pacific storms often result in large rainfalls, coastal and riverine flooding can combine to increase flood hazards near river mouths.

Characteristics of sheltered waters along the Pacific Coast differ from the Atlantic and Gulf coasts. For example, much of the Atlantic and Gulf coasts are characterized by barrier islands, while few barrier islands exist on the Pacific Coast. Also, while 80 to 90% of the Atlantic and Gulf coast shorelines are marshes fringing sheltered waters, less than 20% of the Pacific Coast consists of marsh lands and these are concentrated in lagoons and bays (CEM, 2003). More specific characteristics also differ between the coasts. For example, the inner bars of Pacific Coast inlets are less pronounced than those at Atlantic and Gulf coast inlets (O’Brien, 1976).

Sheltered waters in the State of Washington are predominantly associated with the straits, passages, channels, and islands of Puget Sound. Farther south along the open coast, the large river estuaries of Grays Harbor and Willapa Bay provide sheltered water conditions with jettied and natural inlets. At the Washington and Oregon state border, the Columbia River forms the largest river estuary along the Pacific Coast. Sheltered waters along the coast of Oregon are limited to isolated bays and estuaries associated with rivers flowing out of the Coast Range.

The coastline of Northern California presents more isolated sheltered water areas than the Oregon Coast, with Humboldt Bay as the most significant sheltered water body in this area. The largest sheltered water body in California is the San Francisco Bay. This bay is actually a series of bays, with San Francisco Bay oriented to the south and east of San Francisco, and San Pablo, Suisun, Grizzly, and Honker bays to the north and east and confluencing with the Sacramento and San Joaquin rivers. A series of open embayments characterize the Southern California Coast, the largest of these include Monterey and Santa Monica bays. In the vicinity of Santa Barbara and Los Angeles, a series of large offshore islands provide sheltering effects within the Santa Barbara Channel and Passage, the San Pedro Channel, and the Gulf of Santa Catalina. At the Mexican border, Mission and San Diego bays represent the last major sheltered water bodies along the Pacific Coast.

Although this version of guidance for the Pacific Coast does not specifically address Alaska and the Pacific Islands, the physical setting and coastal flooding processes in sheltered water areas are generally similar, with Alaskan waters further characterized by deep fjords, passages, and inland waterways, and Pacific Island waters by offshore reefs and islands.

D.4.1.2 Pacific Coast Flood Insurance Studies

This subsection briefly introduces Pacific Coast FISs through a discussion of general study considerations, including special considerations for sheltered waters and unique study conditions. Descriptions of typical study scoping activities, hazard zone definitions, and study reporting requirements are also provided. Additional information on flood hazard zone mapping and study documentation is provided in Sections D.4.9 and D.4.10, respectively.

D.4.1.2.1 Study Scoping

Study scoping is defined as the process of determining the extent of a particular coastal FIS and defining the fundamental methodologies to be used in completing the study. As used in this subsection, this process includes two major tasks.

The first task is designed to assess the need for flood hazard mapping for communities and to assign priorities. FEMA has implemented the use of an automated study scoping tool as a module in the Watershed Information SystEm (WISE®) software package to assist Mapping Partners in conducting study scoping. This system provides a consistent methodology for producing a database of information and associated shapefiles that can be used to assess mapping needs. The module can be used to produce reports and maps for community scoping meetings, and to interactively revise and prioritize study reaches during the meetings. The module's ranking tools can be used to assign ranking and funds to community requests and to geographically display the results. The Mapping Partner shall consult with the FEMA study representative to define the appropriate use of the WISE scoping module for a particular study area, including review of previous scoping efforts.

The second task involves determining of general study methodologies based on study area setting, morphology, and coastal processes. This step also includes practical considerations of data availability and data collection needs, as well as study time and budget requirements. Sections D.4.2 and D.4.3 on study methodology and analysis methods shall be consulted by Mapping Partners to determine which methods are appropriate for a particular coastal study setting and their general requirements for data and flooding analysis. In some complex study areas, a scoping phase of the coastal FIS may be needed to determine the availability of data and define a study methodology that combines a number of analysis methods and mapping procedures.

The following general procedures shall be followed for scoping the study methodology:

1. Define the objectives of the study using the scoping module of WISE, information from the communities, and information from the FEMA study representative.

2. Review prior flood studies at the site or in the vicinity.

3. Review the study area setting exposure and shoreline morphology.

4. Make an initial assessment of the probable types and extent of hazard zones in the study area.

5. Identify subregions and reaches based on onshore conditions (e.g., shore geometry, structures), nearshore conditions (e.g., local exposure, profile morphology), and offshore conditions (e.g., depth contours, geometry of sheltered waters).

6. Define potentially applicable study methodologies using Sections D.4.2 and D.4.3 as guidance.

7. Determine data requirements and data availability to support various analysis methods.

8. Assess the probable study methods in terms of level of complexity and probable accuracy of results – in general, the simplest methodology that provides reliable results shall be chosen. Incremental benefits of more sophisticated or detailed analysis may be assessed in this step.

9. Refine selection of analysis methods based on data requirements and reliability to synthesize an overall study methodology that effectively combines multiple analysis methods. For some studies, alternatives to the methods described in this section may be required to address specific situations.

10. Confirm that the study methodology is adequate to support development of anticipated flood hazard zones and produce required mapping.

11. Estimate time and budget requirements.

12. Adjust study extent, data collection, analysis methods, or overall methodology, if necessary, to meet study time and budget constraints.

Some flexibility is desirable in selecting study methodologies with respect to the procedures defined in these guidelines. Overarching considerations in selecting study methodologies shall include a basis in physical processes and quality-assured data, use of technically reliable and current analysis methods, reproducibility using standard engineering methods, verification of results using sensitivity tests and simple checks, and consistency with this appendix and other FEMA guidance.

D.4.1.2.2 Regional vs. Local Studies

Flood insurance studies have usually been performed for a single political jurisdiction, most commonly a county, with the FISs and Flood Insurance Rate Maps (FIRMs) being specifically developed for that community. Adjacent communities have been addressed only insofar as necessary to ensure that Base Flood Elevations (BFEs) match at the study community boundaries. The hydrologic and hydraulic efforts have also typically stopped at the community boundaries, or have extended only so far beyond them as to encompass complete hydrologic units, such as drainage basins, which are necessary to determine conditions within the study community.

This *local study* approach has been followed, in part, due to the demanding computational effort necessary to encompass large regions within the analysis. For example, storm surge calculations require large computational grids, which in turn require large computer capacity and long execution time. To model more than a limited coastal region was difficult or impossible with the computer capabilities of only a few years ago. Similarly, ocean wave simulations have been restricted to limited zones in past studies. Although this community-by-community approach proved tractable, it also introduces some compromise into the studies. For example, a long length of coast that is simulated by breaking it into small sections means that boundary conditions must be specified for each segment, with some probable loss in both efficiency and accuracy.

A second compromise in local studies is that different Mapping Partners may make different assumptions that lead to differences between adjacent studies. Furthermore, not all Mapping Partners have the necessary tools and experience to perform some types of coastal flooding analyses.

The idea of *regional studies* is to perform large-scale regional analyses for certain portions of the engineering tasks needed in a community study and to make these analyses available as input to the local studies. For example, Section D.4.4 of these guidelines describes large regional databases (such as the Global Reanalysis of Ocean Waves [GROW] data) of wave hindcast data. These data can be transformed to the nearshore area, just outside the surf zone, as part of a regional study effort covering a very large portion of the Pacific Coast, using a single, consistent, state-of-the-art methodology. The advent of modern computational abilities makes these regional efforts feasible and more cost-effective than community-by-community repetition of a similar effort.

Regional studies can be implemented to varying degrees. Regional studies need not be as large as an entire coastline or a statewide analysis, but instead might cover a small number of counties. This would be the case if there is a physical characteristic of a region that makes it logical to treat it as a unit, instead of breaking it up into smaller areas. For example, wave studies might be accomplished regionally according to directional exposure, island sheltering, breadth of shelf, or other physical factors. Similarly, tsunami analysis might be done by region according to large-scale tectonic considerations. In a general way, processes that originate in the far field – such as incident waves and tsunamis – are candidates for regional analysis because a single coherent source might affect a large coastal reach. In an event-selection analysis, the selected event might be adopted regionally, controlling behavior within a multi-community basin such as a large sound.

The extent to which regional studies, perhaps focused on particular coastal processes, are available and can be used in local FISs depends on planning and implementation of these studies by FEMA. The Mapping Partner shall consult with FEMA study representatives during the study scoping to determine if relevant regional information or analysis is available and should be incorporated into the study methodology.

D.4.1.2.3 Sheltered Waters

Generally accepted definition for "sheltered waters", which are taken here to include inland waters, enclosed basins, fetch-limited waters, and low-energy beaches, does not exist (Jackson et al., 2002). For the purposes of these guidelines, "sheltered" is assumed to imply a significant sheltering effect on the inland propagation of storm surge, waves, and wind by land masses and vegetation. "Sheltered waters" are water bodies or regions that experience diminished forces from wind and/or wave action relative to the open coast due to the presence of physical barriers, both natural and human, either on land or under water.

Sheltered water areas are exposed to the same flood-causing processes as are open coastlines (high winds, wave setup, runup, and overtopping), but sheltering effects reduce the wave energy and flood potential. The Mapping Partner shall evaluate these potential sheltering effects at both a regional scale and at a local site scale.

At a regional scale, wind-generated waves in sheltered water areas are highly dependent on the shape and orientation of the surrounding terrain to prevailing wind directions. Wave generation and transformation in sheltered waters are usually limited by the open water fetch distance, complex bathymetry, and often the presence of in-water and shoreline coastal structures. Other processes, such as the effects of flood discharges from rivers, can modify local tidal and storm surge elevations, and relatively strong tidal and/or fluvial currents can combine to create tidal and hydrodynamic conditions only found in sheltered water areas.

Bays and estuaries often display significant spatial variability in tidal still water elevations. For example, South San Francisco Bay often exhibits a standing wave with nearly twice the tide range of the central bay and an elevated mean tide and high water elevation compared to the open coast. San Pablo and Suisun bays, to the north and extending into the Sacramento-San Joaquin Delta area, display a progressively muted tidal range and lower elevated mean tide. These effects are the result of the combined effects of complex tidal hydraulics, residual currents, local winds, and river runoff. Oceanic storm surge can also be modified in estuaries, with surge heights sometimes uniformly additive to local tidal datums throughout an estuary, or amplified or muted within a given region of a large estuary.

The Mapping Partner shall review bathymetric and topographic maps and aerial photographs, and make field observations to determine if a coastal flood study site is located within sheltered waters and to assess the degree of sheltering from swell, waves, and wind. The Mapping Partner shall investigate local site scale features contributing to sheltering from wind and waves and affecting flooding at a study site. It is important to note that sheltered water characteristics and processes viewed at a regional scale may be different at a local scale due to site-specific controls (Jackson and Nordstrom, 1992). In general, more detailed examination of local conditions will be required in sheltered waters than on the open coast.

Based on map observations of bathymetry and terrain, the extent of sheltered water areas can be approximately delineated. A rule of thumb for estimating a wind sheltering effect is to assume wind speeds can be blocked if the ratio U/h_m is less than 0.1, where U is wind speed and h_m is the height of the land barrier, in consistent units (CEM, 2003). For example, wind speeds up to 80 mph may be blocked by a land mass 800 feet high. This disruption of the wind creates a boundary layer effect, which can be roughly estimated to extend in the downwind direction a distance approximately 30 times the height of the land mass (CEM, 2003), or for this example, about 4 miles. Mapping Partners shall evaluate the terrain surrounding a flood study site, together with the seasonal direction of local storm winds.

General wave transformation conditions within a sheltered water body may be inferred from wave patterns observed on vertical aerial photographs. During field reconnaissance, the Mapping Partner shall make field observations to identify conditions that affect selection of a study approach. Jackson et al. (2002) have identified characteristics of sheltered water shorelines that may be useful as a guide for field reconnaissance.

The Mapping Partner shall define a general approach to a sheltered water study at the scoping phase of the project. Because sheltered water areas experience the same flood-causing processes as open coast areas, guidance for performing coastal flood studies in sheltered waters is integrated throughout the remainder of these guidelines. Where procedures apply specifically to sheltered waters, they are identified in the individual subsections.

Beyond the initial effort to determine if a study site is located within a sheltered water area, as described above, a general approach to sheltered water studies shall address the following topics:

- **Topography/Bathymetry:** The Mapping Partner shall obtain backshore topography to define hazard zones, obtain nearshore bathymetry to define beach profiles, and define the geometry (size and volume) of the sheltered water body to evaluate hydrodynamic conditions. Detailed bathymetric data will likely be required in tidal inlets to assess their hydrodynamic characteristics, which may control the magnitude and timing of flood components, such as tidal still water levels (SWLs) and wave propagation.

- **Wind:** The climate in sheltered waters is dependent on localized wind conditions, and wave data are typically unavailable at suitable resolution. The study approach will typically focus more on the identification of appropriate wind data sources rather than wave data (as may be relied upon for open coast studies). Accordingly, the Mapping Partner shall identify, obtain, and review available wind data from the nearest appropriate sources; augment long-term data from established weather stations with available short-term data from local governments, industries, or private landowners to verify local wind conditions; and define characteristics related to fundamental wind parameters, such as wind source, seasonal direction, duration, magnitude, and vertical velocity distribution.

- **Tide and Currents:** The Mapping Partner shall identify, obtain, and review available tide gage data to define fundamental tide characteristics, such as astronomical tide, storm surge, tidal amplification, wind setup, and tidal and fluvial currents. Long-term data from established tide stations with observed tides may need to be augmented with data from other sources. In some cases, estimates of natural tidal datums from landscape features, such as mud and vegetation lines, may provide verification of estimated extremal tide elevations.

- **Waves:** The Mapping Partner shall obtain available data on observed wave height, wave length, and wave period, and shall assess probable extreme wave conditions given potential bathymetric and vegetative effects on wave energy.

These general topics can define the forcing functions, boundary conditions, and constraints necessary for analytical and/or numerical modeling approaches to flood determination. Sheltered water physical processes can be complex and may require detailed numerical modeling to define adequately the flood hazards. Given the availability and relative ease of use of modern numerical models, the Mapping Partner shall consider a numerical modeling approach to a sheltered water study where simpler methods do not appear reliable. Model selection shall be made with consideration of the level of complexity of physical processes, data available for calibration, flood risk, and available study budget. If the physical scale of the sheltered water coastal flood study is small and the geographic setting and physical processes are relatively well understood and simple, the Mapping Partner shall confer with the FEMA study representative about the feasibility of using simplified analytical approaches instead of numerical models. A limited analytical approach may also be appropriate to obtain a quick assessment of physical conditions and/or to provide a check of the results from a numerical modeling approach.

D.4.1.2.4 Tsunami Hazards

Much of the Pacific Coast and the sheltered waters along the Pacific Coast are subject to tsunami hazards. The most recent major tsunami to affect the Pacific Coast was the 1964 Great Alaskan Tsunami that affected California, Oregon, and Alaska. Tsunamis are very long waves of small steepness generated by impulsive geophysical events such as earthquakes and landslides. This version of the Pacific Coast guidelines includes a placeholder (Section D.4.8) for future FEMA guidance on tsunami hazards. The Mapping Partner shall confer with the FEMA study representative to discuss treatment of tsunami hazards in a particular study area.

D.4.1.2.5 Debris

Debris entrained in tidal floodwaters and cast inland by wave runup and overtopping is a common phenomenon on parts of the Pacific Coast. Natural debris consists of floating woody debris, such as drift logs, branches, cut firewood, and other natural floatable materials. Masses of drift logs covering large portions of open water have been observed during flood events along the Oregon Coast. Wave-cast beach sediments, such as cobbles and gravel, also constitute natural debris. Debris from human sources may originate from flood damage. This debris may include broken pieces of shore revetment cast inland by extreme wave runup, or floatable materials, such as construction materials, building materials, and home furnishings.

Debris hazards depend on the beach type and configuration, debris sources, the inland extent of wave overtopping, the proximity of insured structures to the shoreline, and the height of the structures above the BFE. At the present time, debris hazards are not explicitly included in FEMA flood hazard zones. However, the Mapping Partner shall note significant debris hazards in a study area and confer with the FEMA study representative, so relevant information may be shared with community floodplain managers.

D.4.1.2.6 Beach Nourishment and Constructed Dunes

Current FEMA policy is not to consider the effects of beach nourishment projects in flood hazard mapping. Beach nourishment, in effect, is treated as a temporary shoreline disturbance, or an “uncertified” coastal structure (a structure not capable of withstanding the base flood event and/or a structure without an approved maintenance plan).

However, given that beach nourishment is being used by more and more communities in response to coastal erosion, it is becoming increasingly difficult to obtain recent topographic data that do not reflect prior beach nourishment. In many communities, beach nourishment has been ongoing for a decade or more (predating the NFIP in some cases).

Mapping Partners should be aware that flood hazard mapping of coastal areas could potentially be affected by various types of beach nourishment, and that current topographic data may reflect beach nourishment efforts.

The Mapping Partner shall determine whether beach nourishment affects a study area, research any beach nourishment projects identified, identify any available data that would allow the performance of the beach nourishment project(s) to be assessed, and determine whether the beach nourishment is likely to persist and to have an effect on flood hazard mapping. If the beach nourishment is determined likely to have an effect on flood hazard zones or BFEs, the Mapping Partner shall contact the FEMA study representative to determine whether an exception to current FEMA policy should be considered.

The presence of constructed dunes in the study area may raise similar questions. For all practical purposes, the Mapping Partner shall treat constructed or reconstructed dunes (referred to as “artificial” dunes by FEMA) as natural dunes would be treated during the FIS. Note, however, the condition of the artificial dune may alter this procedure; NFIP regulations [44 CFR 65.11(a)] do not allow an artificial dune to be considered an effective barrier to coastal flooding unless it has well-established, longstanding vegetative cover, regardless of its size and cross-section.

D.4.1.2.7 Hazard Zone Definitions and Use by FEMA

Coastal flood hazard zones shown on the FIRM are generally divided into three categories: 1) VE zone (the coastal high hazard area); 2) AE zone (and other A zones, where flood hazards are not as severe as in VE zones); and 3) X zone (which is only subject to flooding by floods more severe than the 1% annual chance flood). AH zone and AO zone designations are used in special situations.

Delineation of flood hazard zones involves a set of analyses (waves, water levels, wave effects, and shoreline response) combined into a methodology for a particular study area. The criteria for establishing flood hazard zones are briefly described below. The reader should refer to subsequent sections for a detailed description of the mapping parameters and their derivation.

D.4.1.2.7.1 VE Zone

VE Zones are coastal high hazard areas where wave action and/or high-velocity water can cause structural damage during the 1% annual chance flood. VE Zones are identified using one or more of the following criteria for the 1% flood conditions:

1. The ***wave runup zone*** occurs where the (eroded) ground profile is 3.0 feet or more below the TWL.
2. The ***wave overtopping splash zone*** is the area landward of the crest of an overtopped barrier, in cases where the potential wave runup exceeds the barrier crest elevation by 3.0 feet or more(ΔR>3.0 feet). The landward extent is defined by $y_{G,outer}$ (Section D.4.5.2)
3. The ***high-velocity flow zone*** is landward of the overtopping splash zone (or area on a sloping beach or other shore type), where the product of depth of flow times the flood velocity squared (hv^2) is greater than or equal to 200 ft^3/sec^2.
4. The ***breaking wave height zone*** occurs where 3-foot or greater wave heights could occur (this is the area where the wave crest profile is 2.1 feet or more above the static water elevation).
5. The ***primary frontal dune zone***, as defined in 44 CFR Section 59.1 of the National Flood Insurance Program (NFIP) regulations.

D.4.1.2.7.2 AE Zone

AE Zones are areas of inundation by the 1% annual chance flood, including areas with TWL less than 3.0 feet above the ground, or areas with wave heights less than 3.0 feet. These areas are also subdivided into elevation zones with BFEs assigned. The AE Zone generally will extend inland to the limit of the 1% annual chance flood still water elevation or TWL, whichever dominates.

D.4.1.2.7.3 AH Zone

AH Zones are areas of shallow flooding or ponding with water depths generally limited to 1.0 to 3.0 feet. These areas are usually not subdivided, and a BFE is assigned.

D.4.1.2.7.4 AO Zone

AO Zones are areas of sheet-flow shallow flooding where the product of hv^2 is less than 200 ft^3/sec^2, or where the potential runup is less than 3.0 feet above an overtopped barrier crest (ΔR<3.0 feet). Sheet flow in these areas will either flow into another flooding source (AE Zone), result in ponding (AH Zone), or deteriorate because of ground friction and energy losses to merge into the X Zone. AO areas are designated with 1-, 2-, or 3-foot depths of flooding.

D.4.1.2.7.5 X Zone

X Zones are areas above the 1% annual chance flood level. On the FIRM, a shaded X Zone area is inundated by the 0.2% annual chance flood, and an unshaded X Zone area is above the 0.2% annual chance flood.

Detailed guidance on hazard zone mapping is provided in Section D.4.9.

D.4.1.2.8 Reporting Requirements

Reporting requirements for coastal FISs shall follow guidance provided in Appendix M for the preparation of a Technical Support Data Notebook (TSDN). The TSDN shall consist of the following four major sections, which are more specifically described in Appendix M:

- General documentation;
- Engineering analyses;
- Mapping information; and
- Miscellaneous reference materials.

In general, the material compiled for these sections of a coastal FIS TSDN will be similar to a riverine study, with the exception of the engineering analyses section. The engineering analyses section of a TSDN for a coastal study shall be formatted to reflect the required intermediate data submissions, together with the subsequent correspondence from FEMA and any other subsequent documentation related to a particular intermediate data submission. The purpose and content of individual intermediate data submissions are briefly described below.

Due to the differences between coastal and riverine flood studies and the complexity of coastal studies, intermediate data submissions are required from the Mapping Partner. Intermediate data submissions provide defined milestones in the coastal flood study process where independent reviews are conducted to confirm that the methods and findings are acceptable to FEMA. The primary purpose of this submission and review process is to minimize revisions to analysis methods late in the study.

Coastal analyses involving hydrodynamic modeling for development of water levels and wave processes (transformation, refraction, and diffraction) are highly specialized and complex. Changes or corrections to water-level and wave analyses after they have been used in analysis of shoreline processes and in flood hazard zone mapping are expensive and time consuming. Therefore, FEMA has established intermediate data submission requirements to facilitate review of analysis methods and results at appropriate milestones. The Mapping Partner shall submit the data for FEMA review in accordance with the sequence discussed below.

D.4.1.2.8.1 Intermediate Submission No. 1 – Scoping and Data Review

In this phase of reporting, the Mapping Partner provides the background information on the study setting and available data relevant to the study area. Any new data needed for the detailed coastal analyses in the following phases (offshore waves and water levels and nearshore hydraulics) should be identified in this phase. The study should not proceed until all of the information is available and incorporated in the scoping document for approval.

- **Data Review:** If available at this stage, data may include survey control data, topographic data from aerial photography, LIght Detection and Ranging (LIDAR), and field surveys, and bathymetric survey data. Data shall include available tidal elevation, wind speed, and tidal current data; evaluation of local and regional tide gage records; selection of wind stations in the vicinity of the study area that can provide reasonable length of record, hourly values, and peak gusts to help estimate extreme wind statistics; available tidal current data where currents have a significant influence on coastal flooding potential, including effects on wave refraction and wind wave development; and available historical data (measured and anecdotal) on past coastal flood events.

- **Site Reconnaissance:** The results of the site reconnaissance shall be documented to characterize exposure and coastal morphology; inventory existing coastal structures and levees (including buried coastal structures); identify shorelines where beach nourishment has occurred and could influence coastal flooding analyses and mapping; characterize coastal vegetation where it may influence coastal flooding analyses and mapping; locate analysis transects for subsequent field survey and ultimate use in wave calculations; and identify representative reaches with similar exposure, morphology, and features.

- **Technical Approach:** The submission shall describe the technical approach to analysis of coastal processes and mapping flood hazards in the various settings and shoreline morphologies present in the study area.

D.4.1.2.8.2 Intermediate Submission No. 2 – Offshore Water Levels and Waves

This submission shall be completed before operational modeling runs or computations are performed to transform waves in the shoaling zone and compute wave runup, setup, and overtopping. This submission shall document the selection of offshore water level and wave storm events from data and hindcasts; summarize offshore wave characteristics and statistics; present extremal assessments of wind and wave data; and define input data for restricted fetch analyses.

D.4.1.2.8.3 Intermediate Submission No. 3 – Nearshore Hydraulics

This submission shall be completed before flood hazard mapping is conducted and document the analyses related to: water level and wave analyses to develop base (1% annual chance) flood conditions at the shoreline, including wave modeling for transformation, refraction, diffraction, and shoaling; wave runup, setup, and overtopping assessments in the surf zone; coastal structure and erosion analyses; and inland and overland water level and wave analyses. This submission should include data on control, field, aerial, and bathymetric surveys. It should also include validation of results with available historical flood data, and discussion of modeling results by transect (as needed for interpretation of flood hazards). Where riverine sources influence coastal flood hazard zones in the study area, this submission shall include analysis of riverine flood stages and frequencies.

D.4.1.2.8.4 Intermediate Submission No.4 – Hazard Mapping

This submission will be prepared at the completion of draft delineations of flood hazard zones. The following information shall be submitted to describe the use of analysis results to identify and delineate flood hazard zones:

- **Flood Hazard Zone Limit Identification:** Discuss the determination of hazard zone limits and BFEs resulting from the wave runup analyses and wave overtopping rates determined during the coastal hydraulics phase. Describe the results of coastal flood mapping at shoreline reaches protected by coastal structures (credited or failed). Provide discussion of the values used to define thresholds for the horizontal and vertical limits of the VE zone for wave runup, wave overtopping, and splash zones (at structures). Provide a table of results as a summary by transect of the still water elevation, wave setup, maximum wave crest elevation, wave runup elevations, overtopping rates, maximum shoreward VE zone elevations, and landward VE zone elevations.

- **Flood Hazard Zone Map Boundary Delineation:** Draft work maps for the study area showing all flood hazard zone limits identified along the transects resulting from the detailed analyses and transferred to the topographic work maps. Describe any engineering judgment used to interpolate and delineate hazard zones in between transects including land features that might affect flood hazards, changes in contours, the lateral extent of coastal structures. Provide detailed documentation and technical justification of any adjustments in the hazard zone mapping due to observed historical flood data and/or damages in the study area.

The Mapping Partner will receive review comments within 30 days of the receipt of each data submission. The Mapping Partner shall include the interim review in the project schedule and shall plan the study work to minimize the effect of the reviews on the overall schedule for FIS and DFIRM production. Additional information on reporting requirements is provided in Section D.4.10.